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IN REPLY REFER TO:

ASPECTS OF NASA - OART

SPACE RESEARCH

by

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before

The TAU BETA PI Association
Delaware ALPHA Chapter

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It is certainly an honor and a privilege to talk to you today at the occasion of the initiation ceremonies of your Tau Beta Pi fraternity! Originally, I have been wondering what I, as a technical program manager of NASA, could contribute to such a ceremony. Then I wondered about the Tau Beta Pi at all, remembering a lot of such strange permutations of old Greek letters in all sort of college activities and associations. I thought, then, a man of the fine arts should make a more appropriate dinner speaker, or perhaps so, an expert in educational philosophy.

But after some time of speculation I found that a NASA representative should not be a bad representative at all, and what I first considered to be not appropriate, namely to connect old Greek letters, Tau Beta Pi, with space technology, I found it then to be particularly good. After all, NASA has itself a lot of old Greek things in operation: Centaurs, Atlas', Apollo, and Saturns, just to name a few!

I have been asking myself, why you and so many other student associations do choose such mysterious combinations of old Greek letters to name your society. The reason, I figured, is doubtlessly that you refer to the ancient Greek culture which has been considered by so many philosophers to be the cradle of European civilization. We know, there have been many of such cultural cradles in the world, on the banks of the rivers, Nile, Jordan, Brahmaputra and Yangtze. Each of them has contributed significantly to humanity and civilization, but it appears to be that the ancient Greeks have laid the fundaments to European philosophy, and, in particular, the fundaments of natural philosophy. Aristotle, for instance, has been for more than thousand years unquestioned authority of all mundane and theological scholastic, and it is only very recently that his principles of logic could be expanded and partially be replaced by something even more logical.

Many philosophers believe, therefore, that the ancient Greek School of Systematic Thinking, combined with an open mind for natural observation, is the historical basis of modern science, and, subsequently the basis of our worldchanging technology. This connection of modern engineering with Demokrit, Plato and Aristotle should then, of course, justify the use of Greek letters to name your society!

The world has changed since the days of the great ancient philosophical schools, when the professors could take the liberty to call the classes off, at pleasant weather, and to walk around instead with their students through beautiful gardens while nymphs offered them delicious grapes and wine. The world was smaller too, a flat plate whose rim was not too many miles west of Gibraltar. Although some of the old Greeks already had concluded from unbiased observations that the earth must be spherical, the flat-plate world remained for a long time, and it was manifested, in particular, by Ptolemy, who made the world to be a sort of Houston baseball stadium. Under the influence of early Christian theology, he had to provide geometrical space for the angels too. The first hemisphere above the terrestrial plate was reserved for the stars and other celestrial bodies. The following concentric hemispheres were the room for the heavenly bodies. The angels, by the way, were round balls themselves, because a sphere is the perfect stereometric configuration.

As you know, this marriage of Greek philosophy and Christian theology found great support by the church, and for many centuries this support resulted in a stagnation of scientific progress.

We shall not get here into discussing theological dogmatics, neither should we look upon it with a sort of superior attitude. The occidental world lived in religious devotion. The mind was inverted from outside to inside, and while many great thoughts were produced concerning the eternal problems of the beginning and the end of the world and concerning the sense of life, the observation of nature became unimportant.

The time when the Copernican cosmology was adopted, and when America was discovered, is called the "Renaissance." It was a time when people began to reopen the eyes for the outside and for nature; and it was called "renaissance" because it was a revival of classical ancient Greek principles, particularly concerning the natural philosophy. The Renaissance was the transition from the middle ages to the modern time, a dynamic period concerning not only philosophy and science but also almost all other ways of life. For instance, the gothic style in art and architecture was abandoned and was replaced by revived ancient style elements. The beauty of Italian cities like Venice, Florence and Rome results, to a great extent, from that Renaissance period.

In view of natural philosophy, we can call the Renaissance the birth of modern science and technology. We can draw straight lines from Copernicus to Gallileo, Newton, Maxwell and the modern great minds of physics. The renaissance, with its revival of ancient Greek philosophy, is, so to speak, the great step into new dimensions in the evolution of our occidental culture, leading to the evolution of our industrialized society! It is quite fascinating, then, to observe that the country which was discovered in the trend of that immense cultural transition, is now the leading country in the world, regarding the technological consequences! And, there we are: I am talking to a group of young American engineers who call themselves "Tau Beta Pi," and I feel touched doing so, after all this historical reflections! You may, therefore, allow me to extrapolate such thinking to further development, and let me then envision that our effort to conquer and to explore space might become similarly important as the great discoveries in the Renaissance. We are, indeed, opening new dimensions in technological respect! Whether new dimensions of ideology may follow, remains, of course, pure speculation.

Neither Columbus nor Copernicus could envision an industrialized society, say something like New York City or Kennedy Airport. As little can we foresee what might result from space exploration and space travel in the far future! The discovery of America enlarged the world of 1492 significantly. When we will land on the moon, the inhabitable world will practically not be enlarged. However, it has been proposed that spaceflight might bear even much greater consequences for our evolution than, for instance, Columbus transatlantic trips. One has compared our step by step ventures into the hostile space environment with the step by step expansion of life from the ocean onto land. This is, indeed, a quite fascinating comparison, if we imagine how rough life on the land actually is compared to that in the seas! On land we have the great temperature differences in the air, the storms, the burning sun and we have to carry the weight of the body. How pleasant is, compared to that, the calm floating life in the lukewarm waters! On the other hand, the fish and jelly fish remained extremely dumb, while the land animal, compelled by the need of survival, developed finally to an intelligent being, man! An exception is, of course, the porpoise, who stems from a generation of fluid dynamicists, who decided to go back to the pleasant waters after they solved the turbulent boundary layer problem!

If we now venture into space, we have to solve, in a technological fashion, similar problems as nature solved when life expanded from the waters onto the land. We cannot, of course, wait until the babies are born in a perfect space suit, etc., we have to produce the adaption to space environment ourself, resorting on the skill of modern engineering!

As you well know, everything has to go step by step, building up on the already known, incorporating a bit of new knowledge, and then daring a further step. After all, Columbus had to go via his boat, St. Maria. He could not, jumping right into the jet age, use a DC 8 airplane for his explorations! In practice, scientific and technological progress look evolutionary rather than revolutionary, and a conservative mind may reject the romantic span over centuries and cultures for interpreting technological trends, as I did so far.

However, I will try to give you some evidence to support my thesis that our Space Program indeed opens new dimensions of technological development!

Space flight depends on our capability to escape from the bondage of the earth's gravitational field. Naturally, this bondage is of astronomical magnitude, and until we could produce and manipulate equivalent amounts of energy, space flight had to remain a pure Utopia. From our knowledge about the terrestrial escape velocity, we can immediately derive this characteristic energy. It amounts to an order of magnitude of 100 Megajoules per kilogram of payload. This is an energy which exceeds the energy content of any combustible fuel, and there have been college professors who taught their students that space flight cannot be, because they did not see any fuel which could lift its own weight into space, not to talk about additional payloads! Of course, they overlooked the rocket principle which implies that the vehicle rapidly loses total mass at lift off!

Coming back to our fundamental figure of 100 megajoules per kilogram, we shall consider a typical launch time of, say, 100 seconds. The resulting power requirement is then a Megawatt per Kilogram of spacecraft, or more than 500 horsepower per pound. Let us compare this figure with typical machinery of what I may call conventional technology! An automobile engine or conventional electromagnetic machinery operates at a power level of, perhaps, one horsepower per pound, and one sees that spaceflight requires abruptly a technological power handling capacity of three orders of magnitude larger than we are used to.

We can go a step further and remember fundamental laws of thermodynamics. We find then, that the terrific power of spaceflight and its extreme velocities are inevitably connected with the occurrence of heat. We must therefore be prepared to control temperatures which have never been encountered before in technology!

An appreciation for the energy levels and temperatures encountered in space technology may be obtained from Fig. 1. The first vertical line is a logarithmic scale of the temperature, ranging from absolute zero to a temperature of a billion degrees, at which matter disintegrates down to the atomic nuclei. Accordingly, we have put the states of matter left of this scale, showing at what temperatures it is solid, fluid and gaseous, at what temperatures gases dissociate, at what temperatures gases turn into plasmas, that is, when they become ionized, and finally at what temperature the atomic nuclei disintegrate.

Next to the temperature scale is a scale of velocities, which might also be looked at as a range of kinetic energy. We also have put a scale of power at the right with devices for producing such velocities and kinetic energies. For reference purposes, note in the velocity range the red dotted line marked as "escape velocity." Our concerns are, of course, with temperatures and power levels at the escape velocity and higher, as it projects to both sides from the velocity bracket. The speeds of spacecraft are not much less nor much higher than the escape velocity; however, there are other objects which travel much faster and which have to be included in space technology. They are, for example, meteorites and the solar wind.

The figures corresponding to velocities less than the escape velocity shall mainly provide a reference for comparison with what we are "used to." In terms of temperature, the regime of the "conventional" may well be terminated in the regime of a few thousand degrees, which correspondes, in the velocity scale, to supersonic flight, and to compact engines of several thousand horsepower in the power bracket.

On the other hand, the temperature regime equivalent to the very high velocities, such as those for the meteoroids and solar wind, is the subject of investigations involving advanced plasma physics and, perhaps, devices for thermonuclear fusion.

You may now obtain an appreciation what is ahead of us, venturing into space, and what problems we have to solve!

As most of these problems cannot be solved by applying conventional technology and available engineering skill, we have to carry out a profound research program. I should emphasize, then, that space research has two important aspects: The first concerns the exploration of space itself, namely what we will find and discover out there, the second concerns the means how we will get out there and how we can survive in the space environment. The first aspect of space research is, as I can believe, quite familiar to everyone. I think, however, that the second aspect is by far not well enough recognized in the public. And in view of my historical preambles, I am even inclined to consider the second kind of space research as the one of greater impact on future human society!

NASA has in its organization taken account of these two aspects as shown in figure 2. One sees that our activities are divided into three main programs: Manned Space Flight, Space Sciences, and Advanced Research and Technology. Our Manned Space Flight Program is, of course, the most glamorous, where publicity is concerned. The Space Science Program involves all unmanned spaceflight. Both of these programs represent, so to speak, NASA's hardware, and are, of course, confined in space. The third program, the Advanced Research and Technology, is to my feeling the most dynamical program, as it is concerned with the second kind of Space Age Research, involving both spaceflight technology itself and its reflections to technology in general.

An impression of OART's principle objectives you may obtain from figure 3. As you see here, we are concerned with Space Nuclear Propulsion, Nuclear Systems, Propulsion and Power Generation, Electronics, Space Vehicle Structures, Aeronautics, Biotechnology and, what we call, Basic Research. I am a staff member of that Research Division, which is divided into four branches: Materials, Physics of Fluids, Electrophysics, and Applied Mathematics.

A scholastic physicist may perhaps not appreciate these disciplines of basic research and would rather see: Mechanics, Acoustics, Optics, Electrodynamics, etc. We understand that; however, we cannot afford to operate in the fashion of a beautiful academic formalism. We need specific materials research, because our spacecrafts have to survive under extreme conditions of temperature, strain, particulate irradiation and vacuum. We need physics of fluids research, because we have to control the flow of high energetic gases in high power machinery and around the vehicle at cosmic velocities. We need Electrophysics Research, because we have to look into the macroscopic and microscopic force fields, and we need Applied Mathematics Research in order to find better means to guide our spacecrafts along complicated trajectories.

It is not possible to run through all of our research projects at an occasion like this dinner talk. Let me mention, however, that most of the work is done in our four large research centers: Langley, in Virginia; Lewis at Cleveland, Ohio; Ames at San Francisco, California; and at Marshall in Alabama, and at the Jet Propulsion Laboratory in Pasadena, California. Approximately 20% of our program is done under contract at universities and other research institutions. NASA's program of Basic Research involves approximately 750 scientists and research engineers, and it consists of approximately 450 specialized research tasks.

Instead of mentioning all these 450 tasks, I will present to you quickly some typical problem areas, and I hope that this will give you an impression of what we are doing.

In figure 4 is shown how space technology has increased the number of different material requirements. In 1952, before the advent of spaceflight, only six specific qualities were required in industrial application, for example in airplane design. In 1962, the number of specific material qualities, as required for spacecraft structures, increased to nineteen. Many of such additional requirements result from the need of survival in space environment, for instance under particulate irradiation or evaporation in vacuum. Others are connected with the transversing of vehicles through atmospheric gases at hypervelocities, or they result from the need to conduct and contain high energy gases at the extreme power levels as mentioned before.

We may turn now to one particular material property and show, how through the demands of space technology this property has to be improved, and how, up to now, such improvements have been already achieved. One of the most important examples is the heat resistance of structural elements.

Some typical heat resistance requirements are shown, in figure 5, where operating temperatures and time of endurance are combined. We see that, according to this chart, the greatest temperature occurs in rocket nozzles at 6000°F, and that the structure must withstand that temperature for minutes. Nuclear Electric Generators are expected to operate at 2000°F and shall survive for years.

We may remember now that steel, for example, melts at 2500°F, and that most materials maintain their strength only up to 40-50% of their melting temperature. After all we want the material to do an extraordinary job!

The family of heat resistant materials, that are the materials of very high melting points, may be divided into: Carbons, certain metals and Ceramics.

Let me say something about the Carbon. With a melting point at 6600°F it is one of the most heat resistant materials. However, the strength of this material decreases quickly with temperature, and we cannot use it anymore for structural elements!

In figure 6 is shown how we could improve the situation through material research! The lower curve just shows the strength and temperature relationship of usual graphite. The different levels of that three curves is caused by the porosity of the material. The next curve shows how we could improve the situation through chemical treatment decreasing the porosity, and the upper curve represents the result where the graphite, in addition to the chemical treatment, was plastically deformed to close the porosity and then held at high temperatures until diffusion could heal the defects. The graph indicates, that the high temperature strength could be improved by a factor of ten to hundred.

The other category of heat resistant materials are the refractory metals like tungsten, tantalum and molybdenum. Their melting points are between 5000 and 6000°F. What we are concerned with, is again to maintain the strength at high temperatures so that the material does not become useless at 40-50% of the melting temperatures.

In figure 7 we show the results of alloy research. Again, an impressive improvement has been achieved under the pressure of space technology requirements. Note for instance, that in 1962 a strength of nearly 60,000 psi at 3000°F was achieved, and that today we are close to 70,000 psi at 3000°F. For comparison, I like to remind you that the safety requirements for steel bridges do not call for greater strength than 60,000 psi, at room temperatures, of course, and that, on the other hand, the white hot filaments in electric light bulbs do not burn hotter than 3600°F!

The greatest heat resistance we find among the ceramics. A mixture of Tantalum Carbide and Zirconium Carbide has a melting point at 7100°F. Its strength, however, depends on the relative composition of its molecules. This is shown in figure 8.

There are all the time some molecules present which are missing one or more electronic charges. We call such molecules "ionic." And there are all the time some molecules present which have surplus electronic charges, which we call "covalent." Depending on the relative abundance and on the purity of the correct composition, the strength and other properties vary as shown in the graph. If we could control such abundancies and compositions, we could "engineer" such heat resistant ceramics according with the specific needs of structural requirements. Recent results of material research indicate, that this may, indeed, be achieved, and we show it in figure 9.

We see here, how ceramics may be used in hypersonic aircraft, for the nose, the leading edges of the wings and for reinforcement of the fuel tanks. Also ceramic wool may be used for heat insulation in the fuselage.

I would like to show you now an example of how NASA research has resulted in significant technological achievement of quite general use.

The extrusion capability of metals is doubtlessly an important part of machineability. One sees in figure 10 how under NASA programs progress in extrusion capability, or in the machineability of refractory metals, by far exceeded the progress in average industry, and how over a short time period of less than ten years the impact of space programs advanced general technology!

Switching now to our Fluid Physics Research, I would like to show you the first graph again. Let us look at the horizontal line, marking the escape velocity. If we project this line into the temperature bracket, we are in the order of 100,000°K, extremely higher than the 5000-6000°F, we were concerned within our materials research. From the foregoing we know now, that at the present no material is known which could withstand temperatures up to 100,000°K. Nevertheless such temperatures do occur in spaceflight operations, and since we cannot expose spacecraft structures to such hot gases we have to keep them away. This is, in simple words, one of the main tasks in Fluid Physics Research. Let me give you an example:

One of the most difficult and intriguing problems of space flight, is that of return into the earth's atmosphere, wherein the spacecraft and its inhabitants must be brought to rest from velocities of 20,000 mph or greater. The problem is twofold: one, how to provide a decelerating force of sufficient magnitude to retard the very high energy content of the spacecraft at rates which are within human tolerance, and two, how to prevent the spacecraft from melting and vaporizing in the intense heat produced by compression of the air and friction between the vehicle and the atmosphcre.

To accomplish the deceleration by means of retarding rockets would require so much retarding rocket thrust and weight to make the whole operation unfeasible. If, however, the atmosphere itself is used to slow down the spacecraft, then the problem of protecting the craft from the heat produced becomes tremendous. For example, in returning to earth from orbiting velocity, the energy of the Mercury spacecraft was equivalent to a heat load several times more than enough to vaporize the spacecraft, its contents and any cooling system it could carry. At higher speeds, the problem of course gets worse, in that the heating varies as the cube of the entry velocity.

The solution to the problem of deceleration and heating is symbolically shown in figure 11. It involves the choice of the proper configuration for the spacecraft so that only a small part of the heat produced during re-entry reaches the vehicle, the determination of the flow field about the configuration chosen and third, of course, the provision of an adequate heat protection system to handle that part of the heating load that does reach the spacecraft. With these considerations in mind, the well-known blunt-nosed Mercury capsule was designed.

The blunt-nose on the Mercury capsule solved the deceleration and the major part of the heat problem by creating a strong bow shock wave which unloads a major part of the heat on the atmosphere. As you can see from the artist's sketch in figure 12, the shock wave extends a considerable distance into the atmosphere on either side of the body, leaving a broad wake of heated air that contains as much as 99% of the total heat load, and furnishes 98% of the decelerating force. The stronger the shock wave, the larger the fraction of the total heat load that is transferred to the atmosphere.

In our research we are looking beyond the satellite return speed of the Mercury spacecraft, and also beyond the lunar return speed of Apollo. We are concerned with the speeds corresponding to return from interplanetary flight - about 35,000 m.p.h. We can see from figure 13 that the heating load to a blunt nosed spacecraft goes up at a tremendous rate at the higher speeds, that is, beyond lunar-return speed. The reason for the large increase in heat load with speed is caused by the radiant heat input of the incandescent gas cap that is present behind the bow shock wave. At satellite velocity the gas cap temperature reaches a height of about

11,000°, and the radiant heat input is small compared to compression and frictional heating. At lunar return speed the radiant heat load from the 20,000° gas cap is still smaller than friction heating. At higher speeds, however, radiant heating dominates. A possible solution to the problem is shown in figure 14.

In this figure are compared the heat transfer rate against speed for the blunt-nosed shape and a more pointed shape. It is clear that the more pointed shape is better than the blunt nose at the higher speeds because the bow shock is weaker, thus producing lower radiant heating losses.

There is, of course, an extensive research program going on in entry into the atmospheres of the other planets, with emphasis on Mars and Venus. The problem is made more difficult by the fact that we don't know the composition or atmospheric structure of these planets well enough. The main constituents are thought to be nitrogen and carbon dioxide, however, and entry research studies have been made therefore with various mixtures of these two gases.

The results of one such study is shown in figure 15 which shows that the radiative heating load at the nose of a spacecraft entering into the Martian or Venusian atmosphere would be higher by a factor of 6 compared to that of terrestrial re-entry. Actually, these results are for one entry speed. At higher speeds, the results for N_2-CO_2 mixtures are found to be closer to air because the strongly radiating CN component is dissociated in the higher temperature range.

I would like to talk now about a tough problem in our research, namely, the difficulty of simulating in the laboratory all of the flight conditions that a spacecraft would encounter in re-entry and space flight. Because of this difficulty the researcher must be content to simulate in any one facility just a few of the conditions that he seeks to study, and then use other facilities. There are a number of ingeneous facilities that have been developed for studying the aerodynamic and chemical behavior of high temperature air at high velocities, but the one thing that they have in common is that their test times are rather short. These times are in contrast to the conventional wind tunnels which are essentially continuous flow devices. The reason for the very short test times in the hypervelocity facilities is, as I discussed in the first slide, that the production of the desired velocities and temperatures calls for tremendous amounts of power.

A way to circumvent enormous technological difficulties is simply to produce that power for extremely short times, and as a result our researchers have become quite proficient in taking meaningful measurements in test times of a few millionths of a second.

Figure 16 shows an example of one such facility that has been producing very useful data. Here very small, light-weight models, ranginf from $\frac{1}{4}$ to $\frac{1}{2}$" in diameter, are fired down a long tube at velocities up to about 20,000 mph. These hypervelocity projectors are called light-gas guns because they commonly use hot compressed hydrogen as a propellant. The hydrogen propels the models at accelerations exceeding a million times that of gravity. Although the scale is exceedingly small and the amount of total information that can be obtained in this manner is not great, a facility such as this comes close to duplicating most of the reentry flight conditions.

An advanced version of another short duration facility that is now being built at the Langley Research Center is shown in figure 17. This facility is a version of a shock tube wherein very high temperature, high speed air is produced by the heating and compression of a driver gas through the electrical discharge from a condenser bank. Shock tubes are an excellent source of producing high temperature air, up to about 100,000°. This facility will be capable of investigating radiation from air at temperatures characteristic of velocities in excess of 40,000 mph, and for carrying on other gas dynamic studies.

Hot gas flow physics is also inherent in advanced propulsion systems, whether they be advanced airbreathing engines for the supersonic transport or for recoverable boosters, or for chemical, electrical or nuclear rockets.

Figure 18 is a sketch of an experimental facility that was designed to study flow and heat transfer in very hot gases under the influence of accelerating and decelerating pressure gradients. In this facility gas is heated by means of an electric arc to as much as 25,000°F, passes into a mixing chamber and then on through a convergent-divergent nozzle. Temperature, pressure, heat transfer and spectroscopic measurements are made along the length of the channel. These measurements, together with accompanying analyses, are necessary for the design of nozzles that will be efficient from the standpoint of thrust production and at the same time, will be able to stand up under the intense heat load of the hot gases.

Going further in temperature and velocity, we enter the plasma regime, as you may recall from our first chart. A plasma is created, when the internal energy of a gas increases to the degree where an appreciable fraction of the gas becomes ionized. An ionized gas, or a plasma, can conduct electric currents. By applying magnetic fields to such current carrying plasmas, we can exert on them an electromagnetic body force, similarly as it happens to the armature of an electric motor.

Several great advantages result potentially from this possibility of electromagnetic interaction: One possibility is to use this body force for controlling and channeling the flow of extremely hot gases, by means of magnetic fields.

And since magnetic fields do not suffer from heat, we could virtually handle gas flow problems involving any temperature. As you might expect, the plasmas have their own problems, and where magnetic confinement and flow control is concerned this is predominantly a stability problem. Extensive research is going on to understand the nature of plasmas and to disclose the physics which underlie possible stability criteria.

The other great advantage of plasma dynamics is the possibility of accelerating or decelerating the ionized gas by means of electric power input or electric power extraction.

Looking at the case of plasma acceleration, we may notice a fundamental difference between the electromagnetic body forces and the forces in conventional gas acceleration, the expansion through convergent-divergent nozzles. In the latter case, one cannot achieve a kinetic energy of the exhaust larger than the enthalpy before expansion, that means, larger than the equivalent heat of the combustion gases in the burner. Electromagnetic plasma acceleration is free from this restriction. We can already accelerate a plasma to velocities equivalent to temperatures of millions of degrees. This is shown in figure 19. An electromagnetic plasma accelerator produces a burst of ionized gas at an initial temperature of some 20,000°K, and at a velocity in excess of 500,000 miles per hour. This velocity corresponds to a temperature greater than a million degrees. At sudden stop at a magnetic barrier, the directed high energy must become randomized producing for a microsecond a temperature of million degrees. The reason for the short duration is, apart from power requirements, the rapid cooling of the plasma through radiation losses. As a matter of fact, such experiments are frequently designed for studying radiation from plasmas.

The investigation of radiation is, of course, of great interest for space exploration, because space is - so to speak - "filled" with all sorts of radiation. Most of this radiation originates from hot and very hot gases, that is, from plasmas. An outstanding example is our sun, itself being a great big blob of plasma. Its radiation, as everyone knows, makes our earth inhabitable for life, and it is, practically, the ultimate source of all the energy we use, including that from coal and oil. The study of the radiation from a plasma is therefore one of our prime tasks.

A better experiment for producing a very hot plasma for radiation studies is shown in Figure 20. Again use is made of electrical power, but the plasma is not accelerated. Rather, for purpose of heating, it is compressed by the forces of tremendous magnetic fields produced by an instantaneous power-input of approximately 100 million horsepower. For a flashing fraction of a second a plasma is then created which, at a temperature of million degrees, simulates to a high degree the conditions of the sun's corona. Studies of the radiation can be made readily, and it is expected that they are representative of actual solar radiation.

You may remember from the first chart, that the temperature of the interior of the stars is between some ten million degrees and a hundred million degrees. The chart showed also that this corresponds to the range of cosmic velocities, for instance to the velocity of the solar wind. At the equivalent energies, matter turns into the plasma state or even into the state where nuclear reactions take place. We should expect therefore that the matter out there in space exists predominantly in the form of a plasma. And that is actually the case, as is shown in the last figure. Here it is shown that more than 99% of the universe consists of plasma, which means that most of the matter in the world exists at a much higher energy level than we are used to from our terrestrial environment. One may say equivalently, that the universe is much much hotter and that physical interactions are much more violent than it is on the earth's surface.

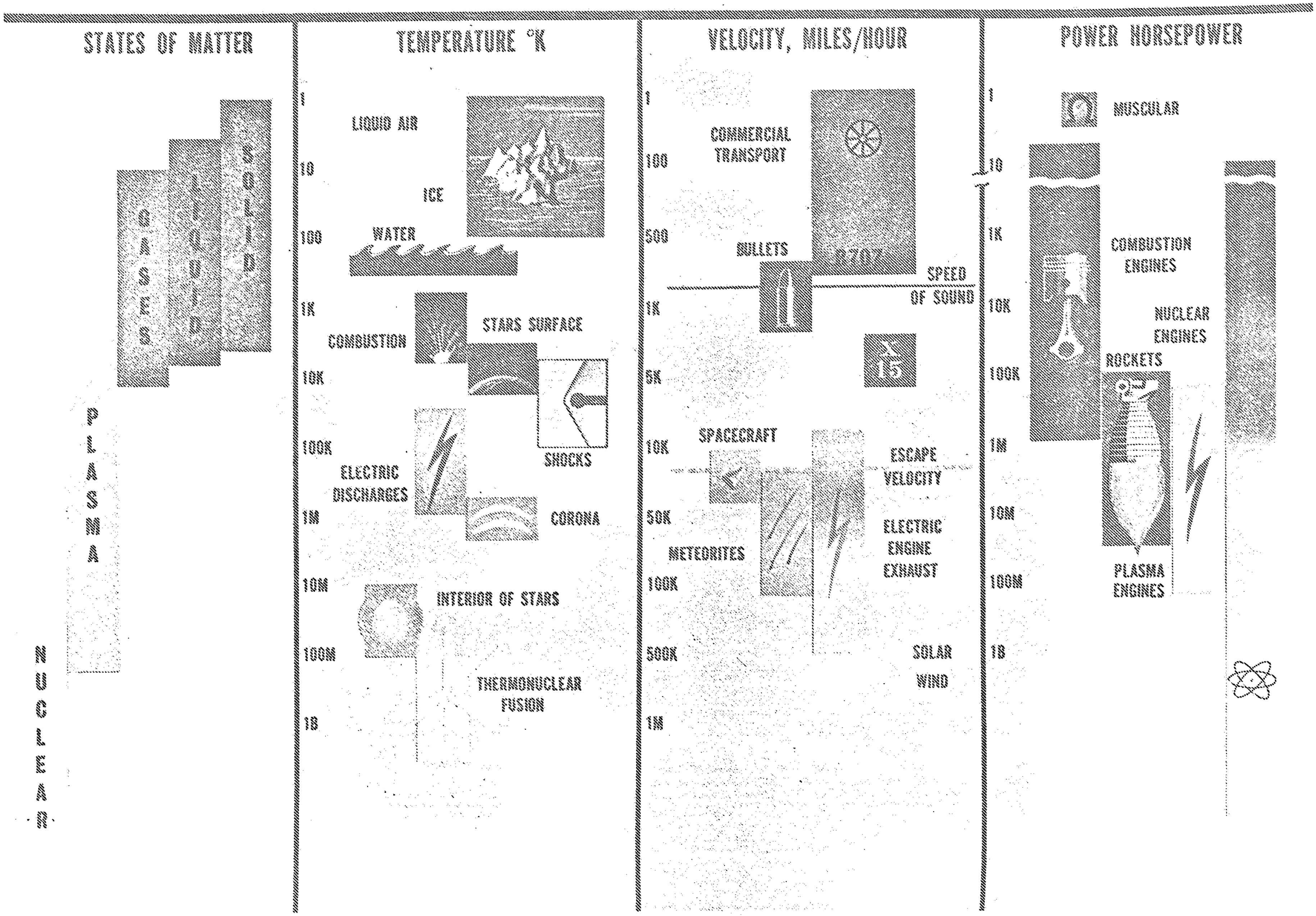
We should not be surprised at this! Life is the most delicate thing which nature has produced. Our terrestrial world is a soft world, a world of pleasant lukewarm compared to space, as the water of the oceans appeared to be pleasant and lukewarm as compared with the life on land!

Whether spaceflight and space exploration will result in drastic changes of our cultural evolution, is, as I said, pure speculation. In any case, however, our space program represents the greatest challenge for science and technology ever known!

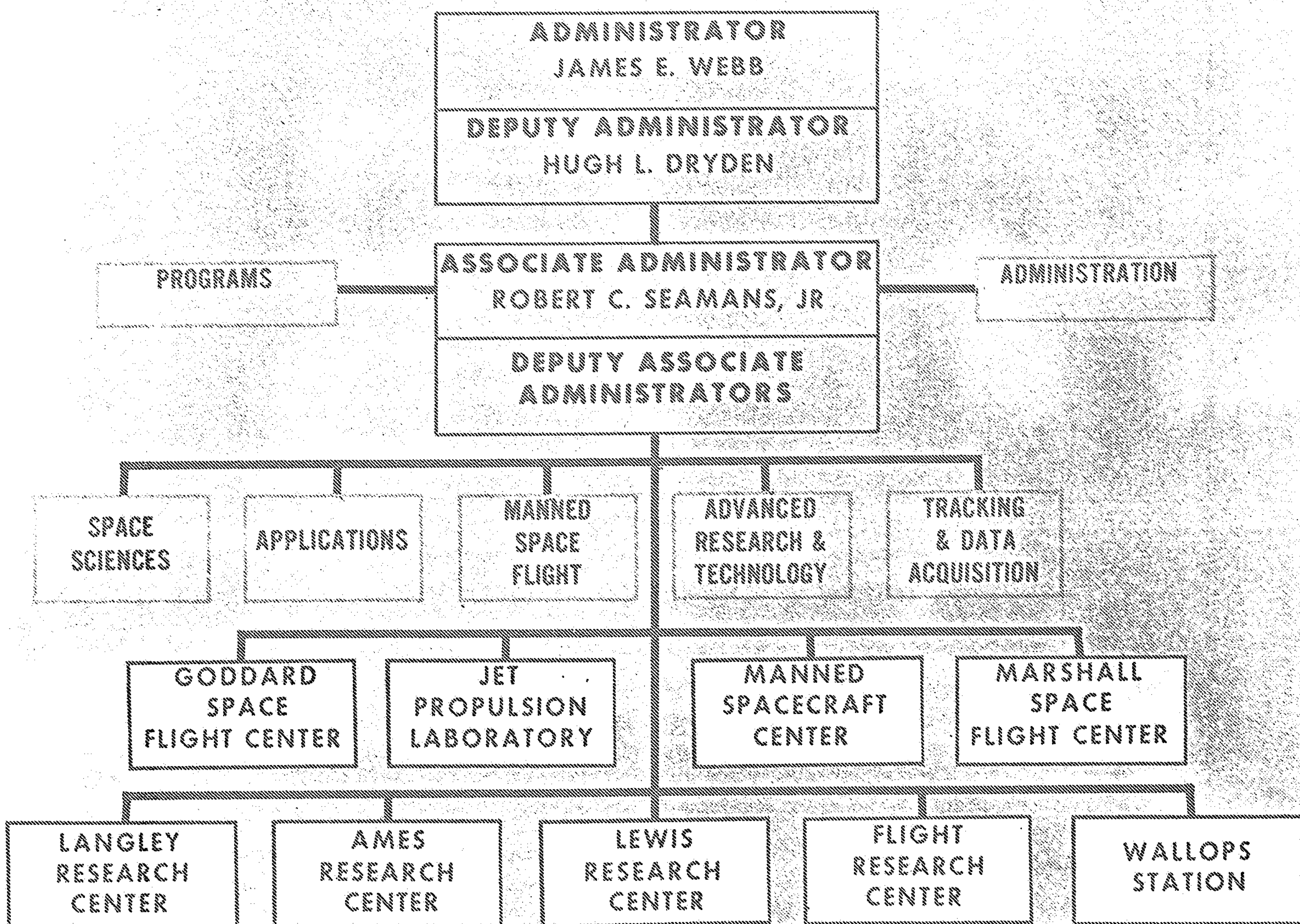
I like then to congratulate you that you are finishing your education in engineering and science at the advent of space flight, and I like to congratulate you particularly that you were elected for the Tau Beta Pi membership in the time of greatest scientific and technological challenge.

Thank you very much!

TEMPERATURE & POWER IN SPACE TECHNOLOGY



NASA OPERATING ORGANIZATION



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SIGNIFICANT PROPERTIES OF AEROSPACE STRUCTURAL MATERIALS

	1952	1957	1962
STRENGTH	•	•	•
DENSITY	•	•	•
ELASTIC MODULUS	•	•	•
CORROSION RESISTANCE	•	•	•
DUCTILITY	•	•	•
FATIGUE RESISTANCE	•	•	•
OPTICAL PROPERTIES		•	•
ABLATION PROPERTIES		•	•
RADIATION RESISTANCE		•	•
VAPOR PRESSURE		•	•
SPECIFIC HEAT		•	•
THERMAL SHOCK RESISTANCE		•	•
IGNITION CHARACTERISTICS		•	•
CREEP STRENGTH			•
METEOROID IMPACT RESISTANCE			•
REACTION TO IONIZED GAS			•
THERMAL CONDUCTIVITY			•
RADIATION SHIELDING ABILITY			•
CRYOGENIC PROPERTIES			•

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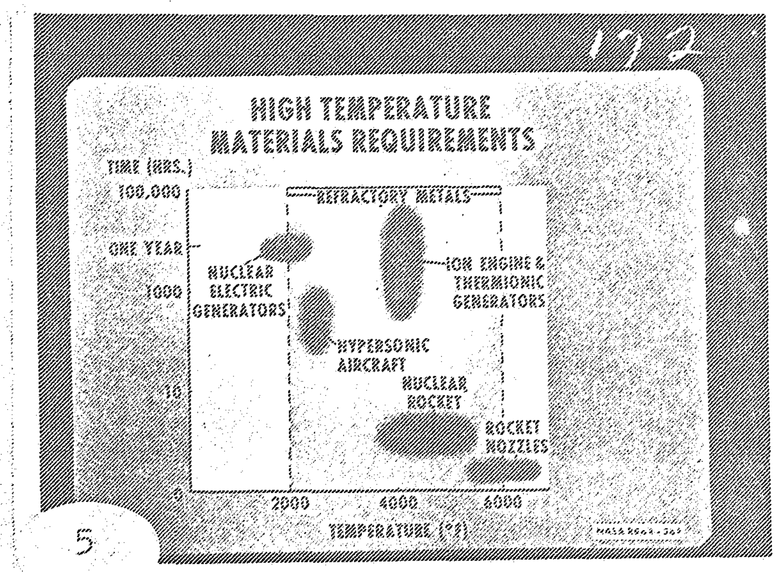

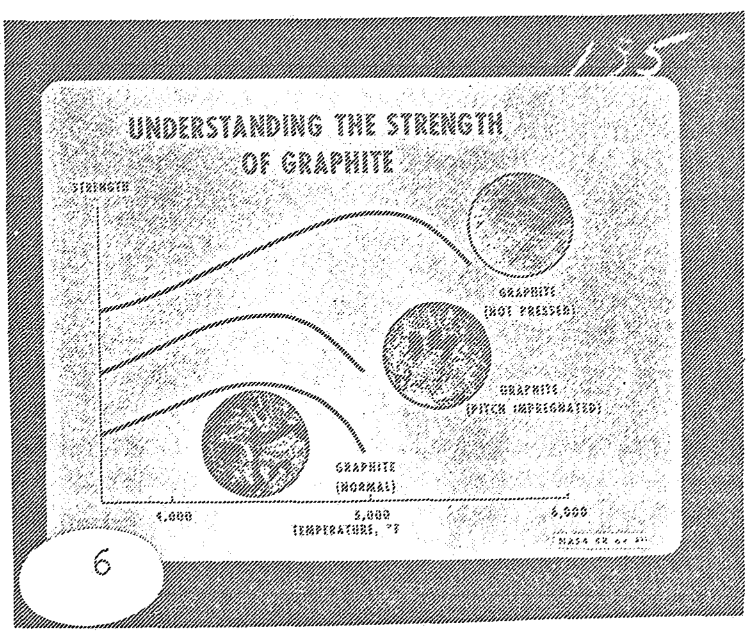

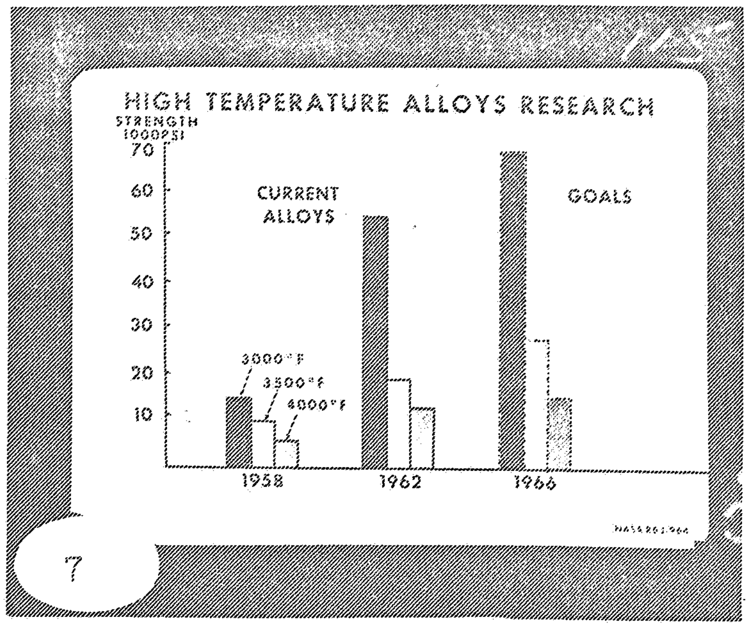
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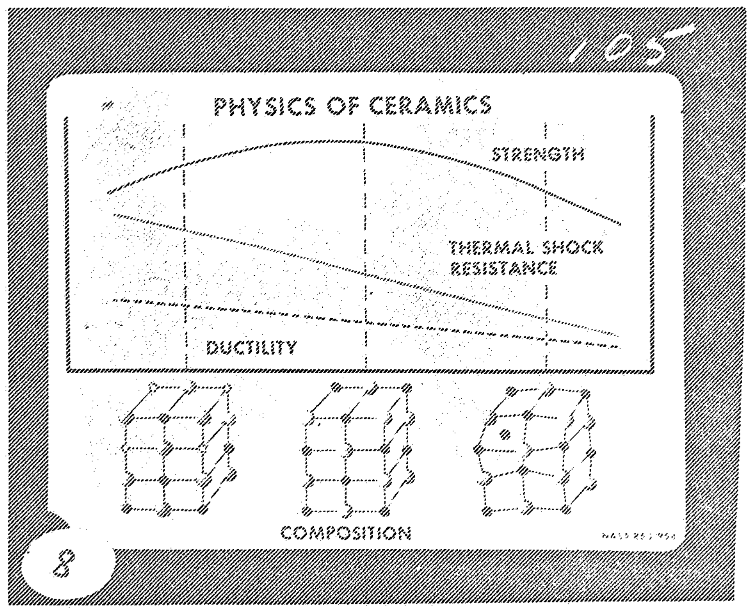
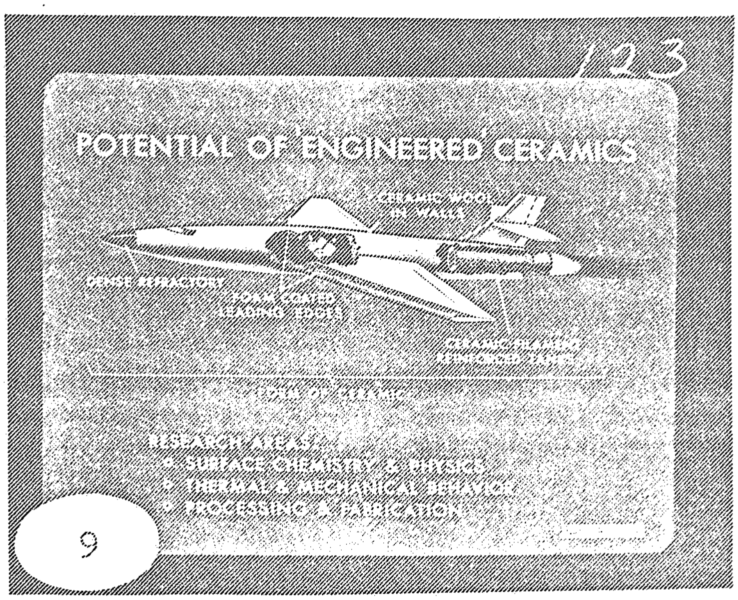
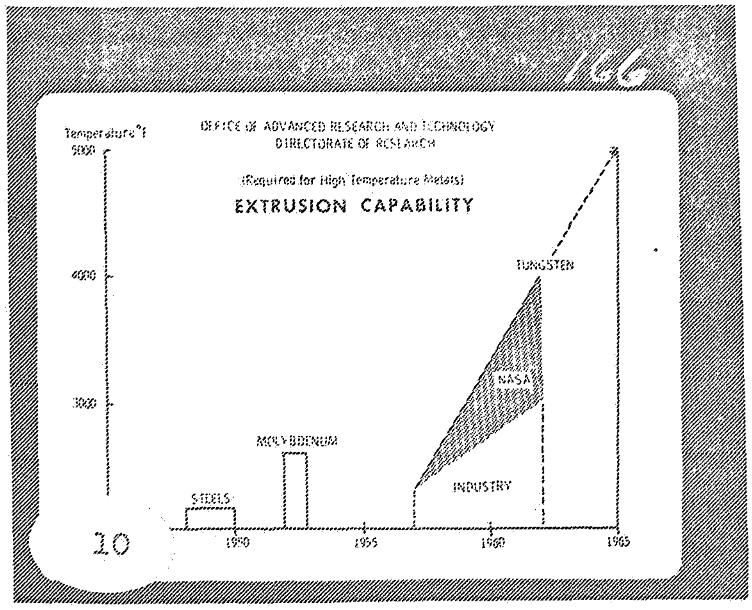
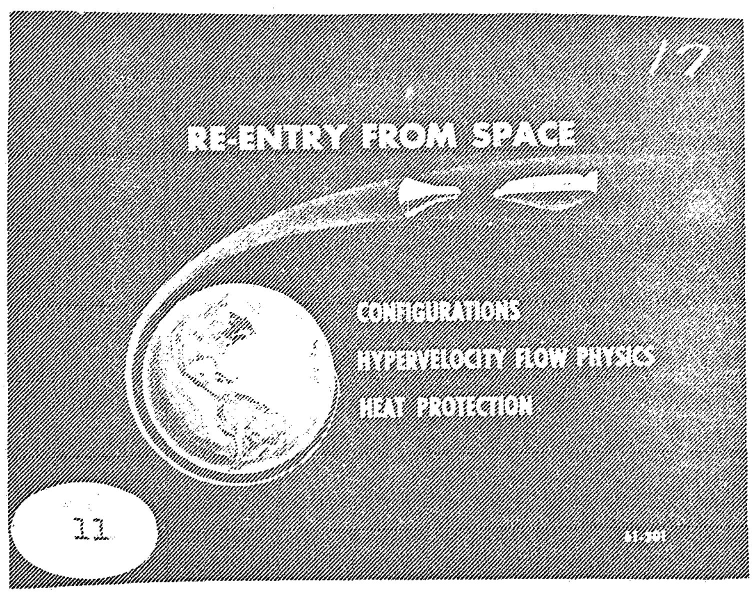
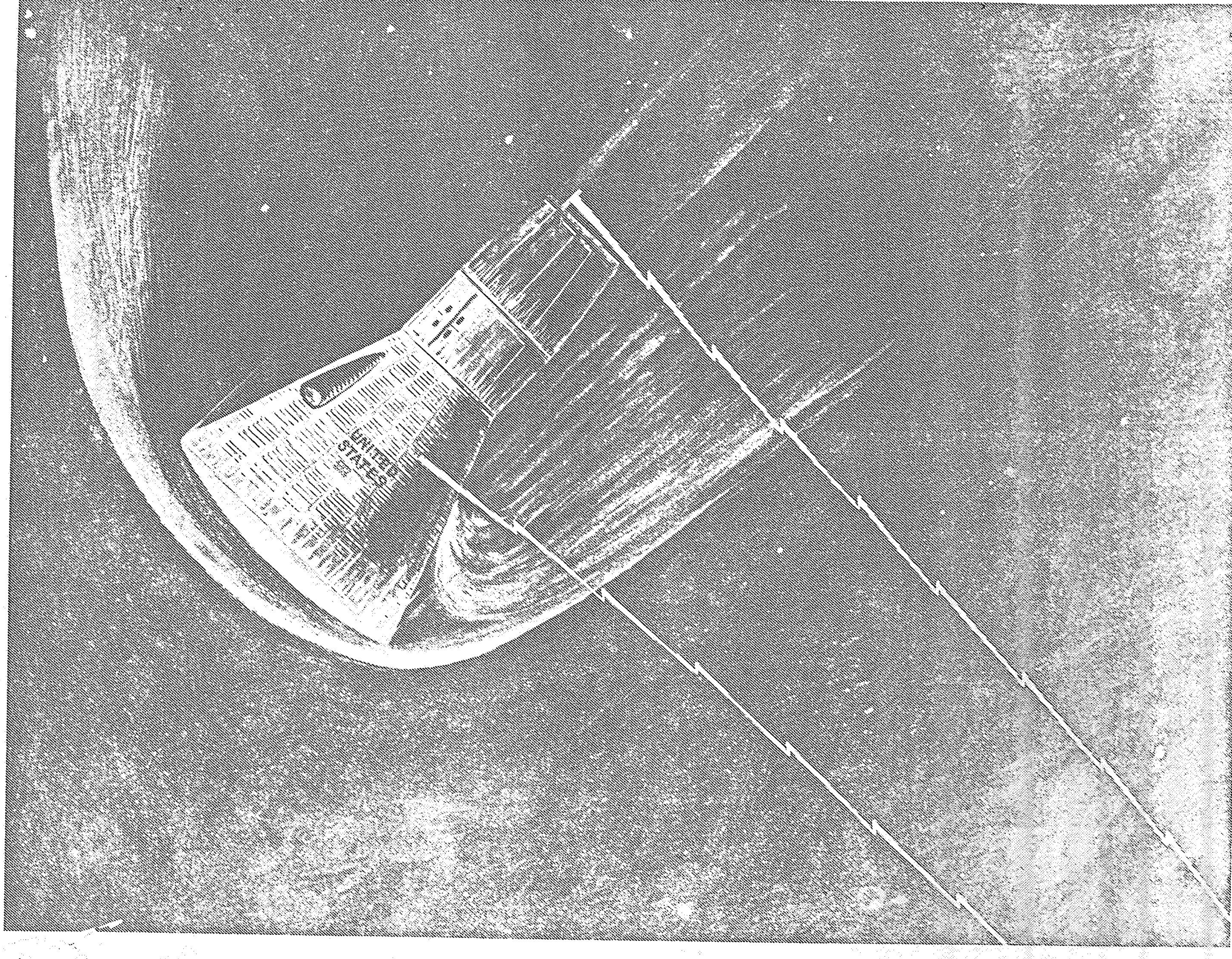
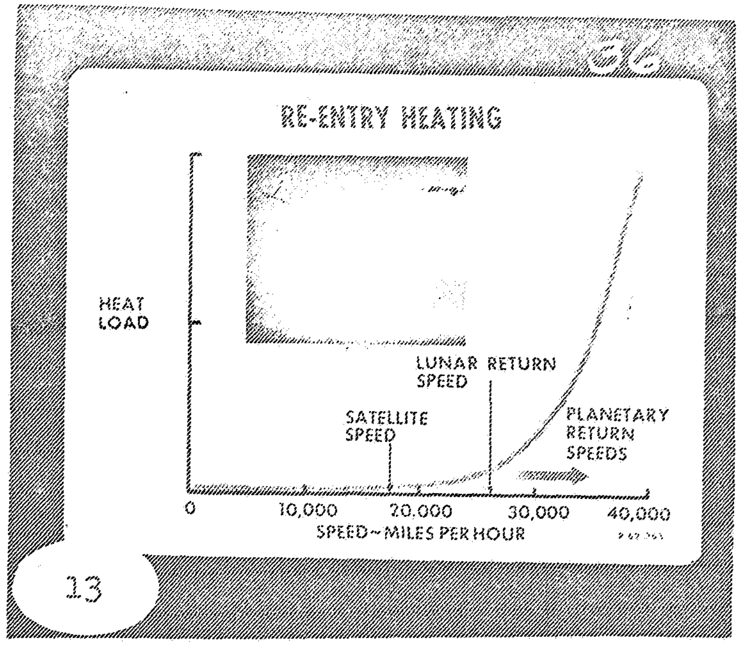

105
PHYSICS OF CERAMICS
STRENGTH
THERMAL SHOCK RESISTANCE
DUCTILITY
COMPOSITION
8

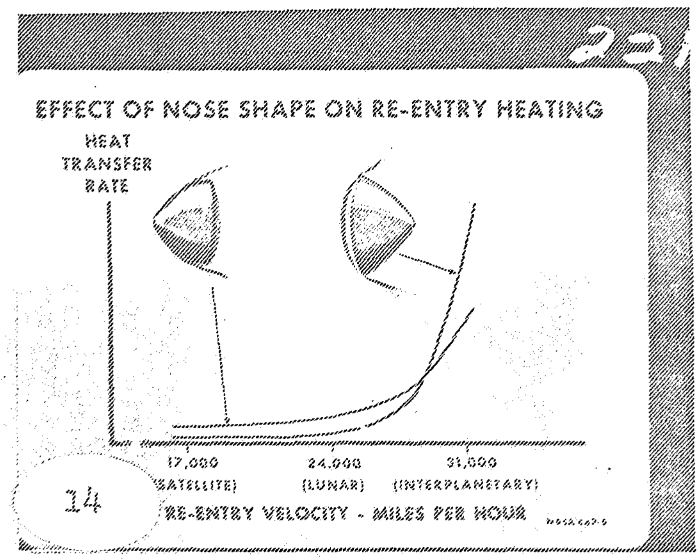

123
POTENTIAL OF ENGINEERED CERAMICS
CERAMIC WOOL IN WALLS
DENSE REFRACTORY
FOAM COATED LEADING EDGES
RESEARCH AREAS
• SURFACE CHEMISTRY & PHYSICS
• THERMAL & MECHANICAL BEHAVIOR
• PROCESSING & FABRICATION
9

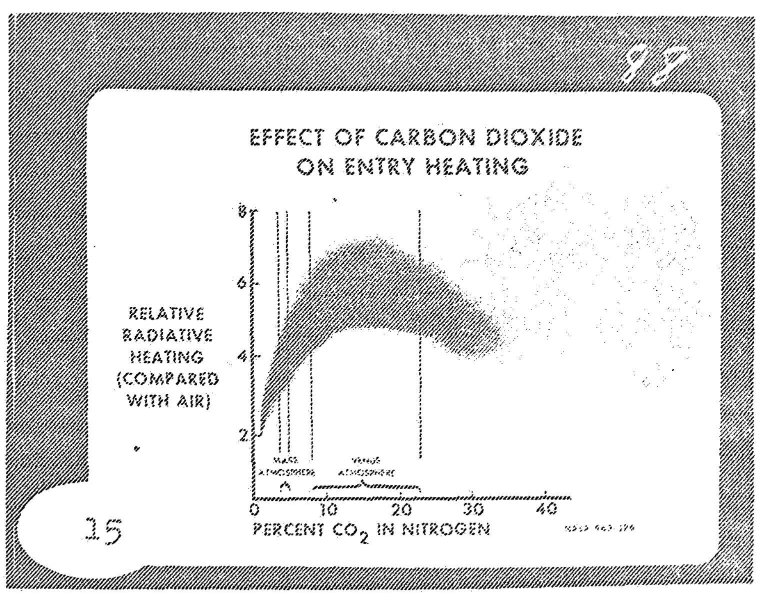

166
OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY
DIRECTORATE OF RESEARCH
(Required for High Temperature Metals)
EXTRUSION CAPABILITY
Temperature °F
5000
4000
3000
TUNGSTEN
NASA
MOLYBDENUM
INDUSTRY
STEELS
1950
1955
1960
1965
10

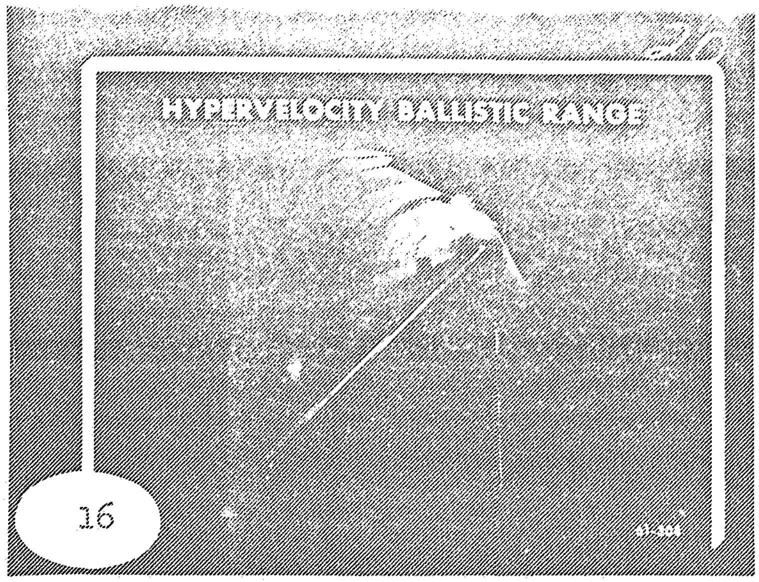

17
RE-ENTRY FROM SPACE
CONFIGURATIONS
HYPERVELOCITY FLOW PHYSICS
HEAT PROTECTION
11

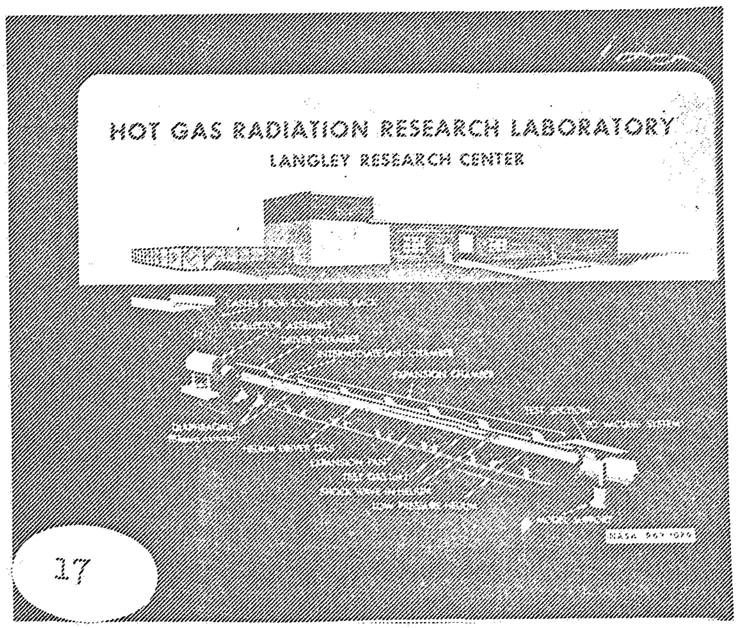

UNITED
STATES

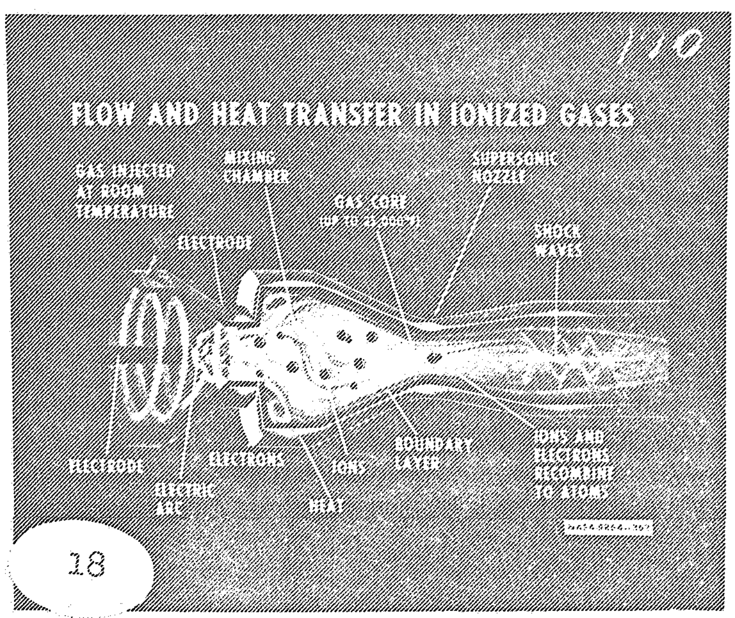

RE-ENTRY HEATING
HEAT LOAD
LUNAR RETURN SPEED
SATELLITE SPEED
PLANETARY RETURN SPEEDS
0
10,000
20,000
30,000
40,000
SPEED ~ MILES PER HOUR
13

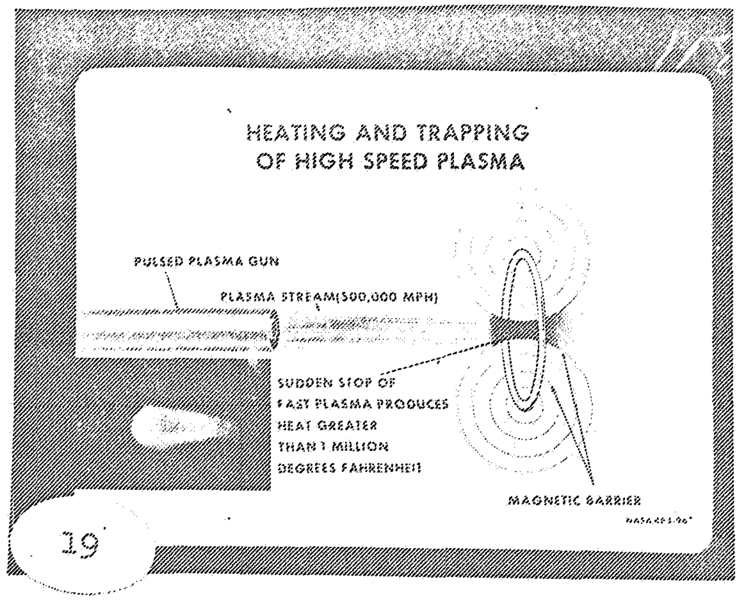

EFFECT OF NOSE SHAPE ON RE-ENTRY HEATING
HEAT TRANSFER RATE
17,000 (SATELLITE)
24,000 (LUNAR)
31,000 (INTERPLANETARY)
RE-ENTRY VELOCITY - MILES PER HOUR
14

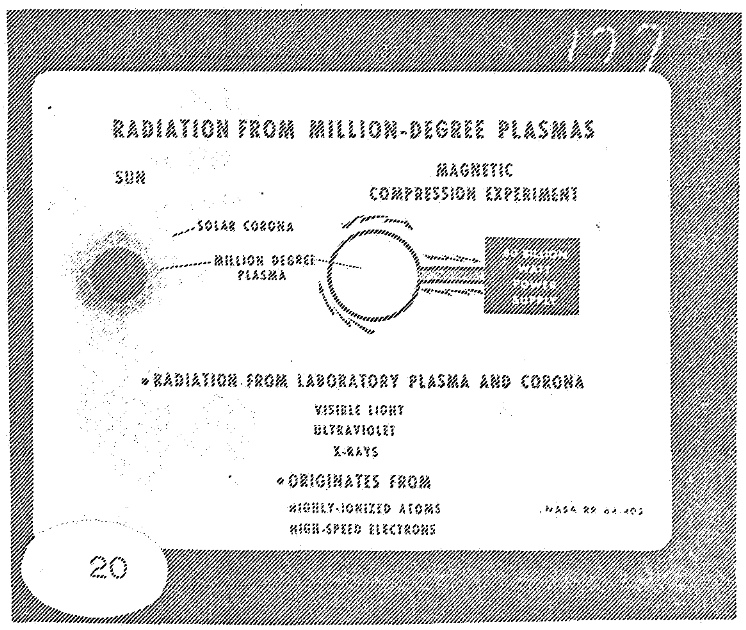

EFFECT OF CARBON DIOXIDE ON ENTRY HEATING
RELATIVE RADIATIVE HEATING (COMPARED WITH AIR)
8
6
4
2
0
10
20
30
40
PERCENT CO2 IN NITROGEN
15

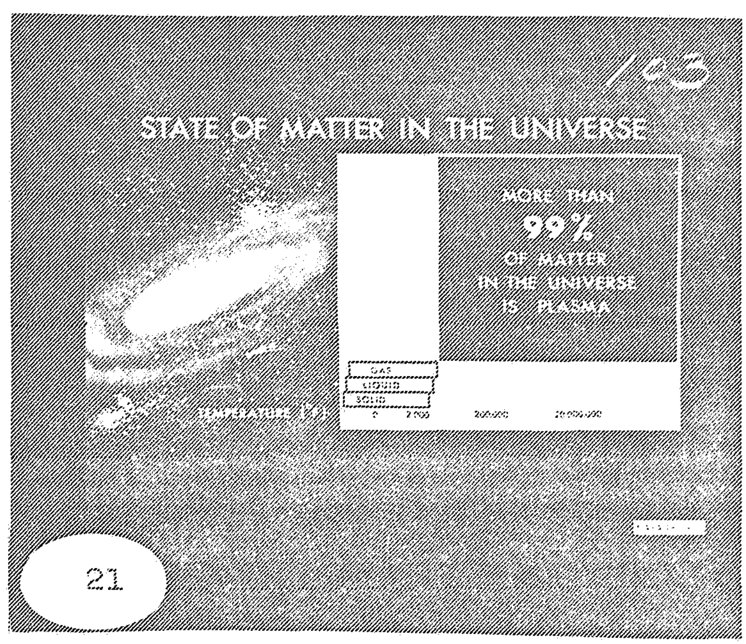

HYPERVELOCITY BALLISTIC RANGE
16


HOT GAS RADIATION RESEARCH LABORATORY
LANGLEY RESEARCH CENTER
EXPANSION CHAMBER
TEST SECTION
17


110
FLOW AND HEAT TRANSFER IN IONIZED GASES
GAS INJECTED AT ROOM TEMPERATURE
MIXING CHAMBER
SUPERSONIC NOZZLE
GAS CORE
ELECTRODE
SHOCK WAVES
ELECTRODE
ELECTRIC ARC
ELECTRONS
HEAT
IONS
BOUNDARY LAYER
IONS AND ELECTRONS RECOMBINE TO ATOMS
18


HEATING AND TRAPPING
OF HIGH SPEED PLASMA
PULSED PLASMA GUN
PLASMA STREAM(500,000 MPH)
SUDDEN STOP OF
FAST PLASMA PRODUCES
HEAT GREATER
THAN 1 MILLION
DEGREES FAHRENHEIT
MAGNETIC BARRIER
19


RADIATION FROM MILLION-DEGREE PLASMAS
SUN
MAGNETIC
COMPRESSION EXPERIMENT
SOLAR CORONA
MILLION DEGREE
PLASMA
•RADIATION FROM LABORATORY PLASMA AND CORONA
VISIBLE LIGHT
ULTRAVIOLET
X-RAYS
•ORIGINATES FROM
HIGHLY-IONIZED ATOMS
HIGH-SPEED ELECTRONS
20


163
STATE OF MATTER IN THE UNIVERSE
MORE THAN
99%
OF MATTER
IN THE UNIVERSE
IS PLASMA
GAS
LIQUID
SOLID
TEMPERATURE
21